National Aeronautics and Space Administration

Technical Progress and Accomplishments of NASA's Fixed Wing Project

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51st AIAA Aerospace Sciences Meeting
GEPC-02: Progress Towards N+3 Technologies in NASA's Subsonic Fixed Wing Project
January 7, 2013
Grapevine, TX

www.nasa.gov

Outline

- Overview
- Technical Challenges
- Technical Highlights
- Concluding Remarks

The Fixed Wing Project

Explore and Develop Technologies and Concepts for Improved Energy Efficiency and Environmental Compatibility for Fixed Wing Subsonic Transports

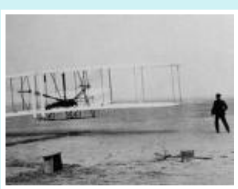
Vision

- Early-stage exploration and initial development of game-changing technology and concepts for fixed wing vehicles and propulsion systems

Scope

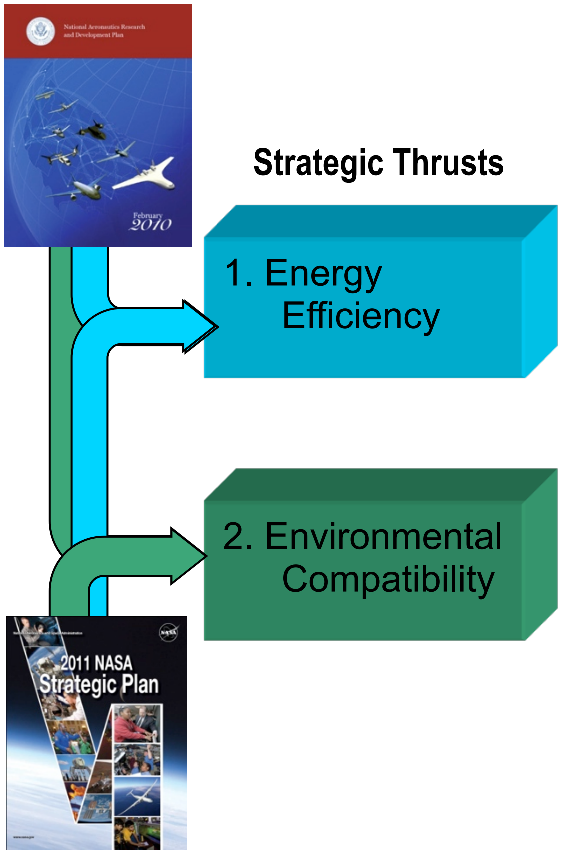
- Subsonic commercial transport vehicles (passengers, cargo, dual-use military)
- Technologies and concepts to improve vehicle and propulsion system energy efficiency and environmental compatibility
- Development of tools as enablers for specific technologies and concepts

Evolution of Subsonic Transports



1903 — 1930s — 1950s — 2000s

NASA Subsonic Transport System Level Metrics



TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

Research addressing revolutionary far-term goals with opportunities for near-term impact

N+3 Advanced Vehicle Concept Studies

Summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 Entry into Service (EIS)

Boeing, GE, GA Tech

NG, RR, Tufts, Sensis, Spirit

GE, Cessna, GA Tech

MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT

NASA

Trends:

- Tailored/Multifunctional Structures
- High AR/Laminar/Active Structural Control
- Highly Integrated Propulsion Systems
- Ultra-high BPR (20+ with small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements

Advances required on multiple fronts…

Fixed Wing Project Research Themes

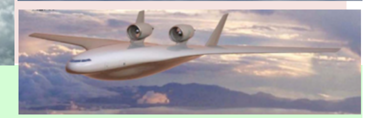
based on Goal-Driven Advanced Concept Studies

Goals *Metrics (N+3)*	*Noise*	*Emissions (LTO)*	*Emissions (cruise)*	*Energy Consumption*
	Stage 4 – 71 dB cum	*CAEP6 – 80%*	*2005 best – 80%*	*2005 best – 60%*

Goal-Driven Advanced Concepts *(N+3)*





Research Themes

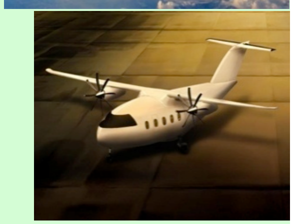
Research Theme 1 (2030): Lighter-Weight, Lower-Drag Fuselage

Research Theme 2 (2030): Higher Aspect Ratio Optimal Wing

Research Theme 3 (2030): Quieter Low-Speed Performance

Research Theme 4 (2030): Cleaner, Compact, Higher BPR Propulsion

Research Theme 5 (2030): Hybrid Gas-Electric Propulsion



Research Theme 6 (2030): Unconventional Propulsion-Airframe Integration

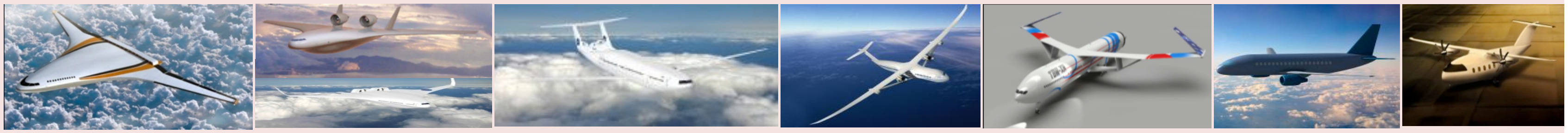
Research Theme 7 (2015): Alternative Fuel Emissions

Fixed Wing Portfolio Addressing N+3 Goals

broadly applicable subsystems and enabling technologies

Goals *Metrics (N+3)*	*Noise*	*Emissions (LTO)*	*Emissions (cruise)*	*Energy Consumption*
	Stage 4 – 71 dB cum	*CAEP6 – 80%*	*2005 best – 80%*	*2005 best – 60%*

N+3 Vehicle Concepts



Research Themes	Lighter-Weight Lower-Drag Fuselage	Higher Aspect Ratio Optimal Wing	Quieter Low-Speed Performance	Cleaner, Compact, Higher BPR Propulsion		Hybrid Gas-Electric Propulsion	Unconventional Propulsion-Airframe Integration	Alternative Fuels
Technical Challenges	Fuselage Structural Weight -15%	Optimal Aspect Ratio +50 to 100%	Community Noise -12 dB, Cum	Low NOx Fuel-Flex Combustor CAEP6 -80%	Compact High OPR (50+) Gas Generator	Elec. Motor Power Density +100%	Integrated Boundary Layer Ingestion System	Alternative Fuel Emissions at Cruise
Technical Areas	Tailored Load Path Structure	Aerodynamic Shaping	Active Flow Control		Hot Section Materials	Electric System Materials	Aerodynamic Configuration	Emissions & Performance
		Adaptive Aeroelastic Shape Control	Airframe Noise		Tip/Endwall Aerodynamics	Electric Components	BLI Inlet/Distortion Tolerant Fan	
		Tailored Load Path Structure	Acoustic Liners & Duct Propagation	Fuel-Flexible Combustion			Propulsion Airframe Aeroacoustics	
		Designer Materials						
		Active Structural Control						
(below dashed line)	Designer Materials				Core Noise	Power Management & Distribution	Adaptive Fan Blade	Fuel Properties

Aero

Struc

Prop

Clean

Quiet

Note: Items below dashed line are other research theme investments (ORTI)

Technical Challenges

TC1.1(FY17): Fuselage Structural Weight -15%, TRL 4

Objective

Aero | **Struc** | Prop | Clean | Quiet

Explore and develop structural technology concepts enabled by emerging advanced manufacturing capability to directly reduce aircraft operating empty weight

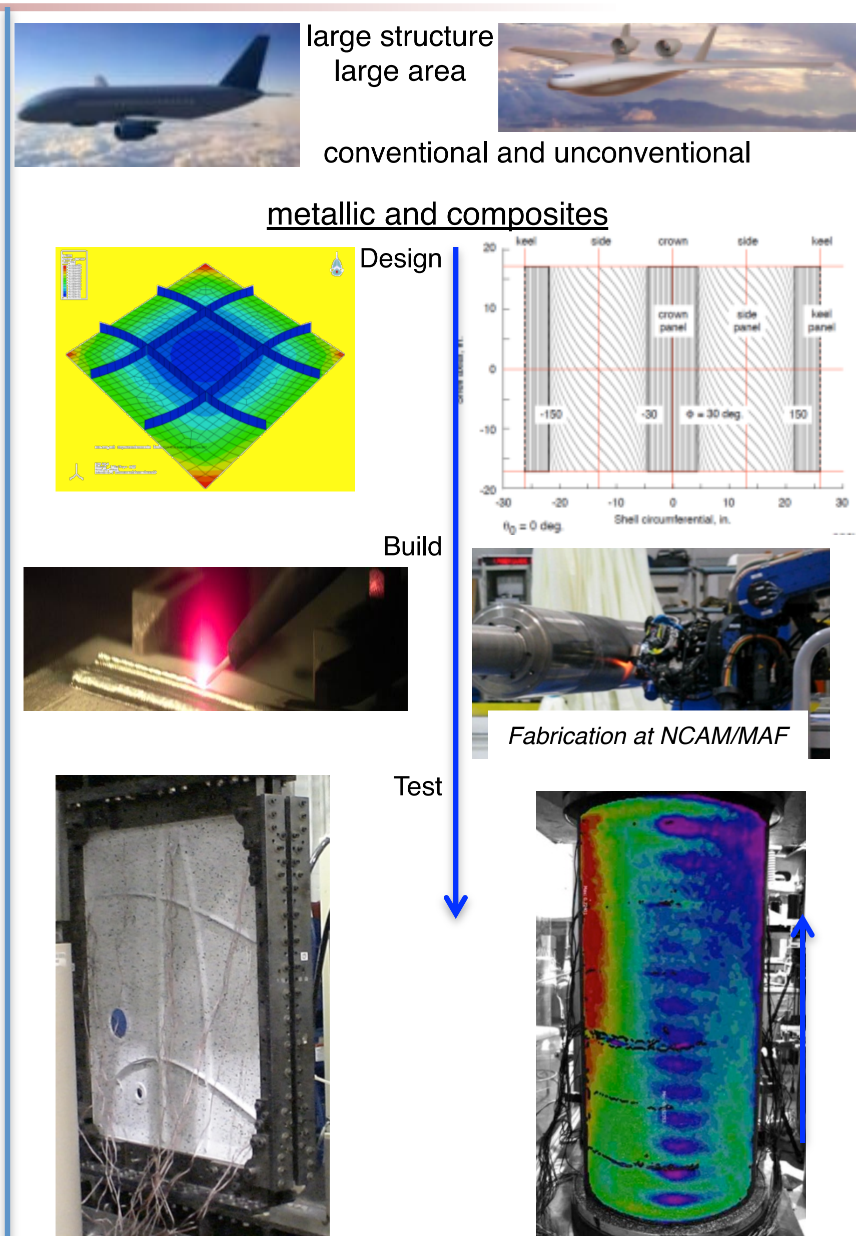
Technical Areas and Approaches

Tailored Load Path Structure

- Curvilinear, metallic stiffeners
- Tow-steered carbon fiber

Benefit/Pay-off

- 15% fuselage structural weight reduction relative to conventional composite structure
- Validated design methodology can be applied immediately and will be applicable to future designer materials for greater benefit



TC2.1(FY19): Optimal Aspect Ratio +50 to 100%, TRL 3

Objective

Aero | Struc | Prop | Clean | Quiet

Explore and develop aerodynamic, structural, and control technologies to expand the optimal wing system drag/weight design trade space for reduced energy consumption

Technical Areas and Approaches

Tailored Load Path Structure
- Passive aeroelastic tailored structures

Designer Materials
- Variable stiffness flexible skins

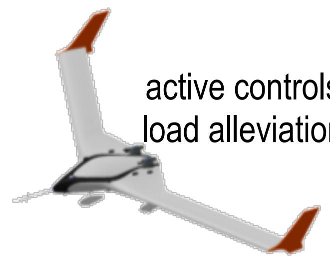
Active Structural Control
- Distributed control effectors, robust control laws
- Actuator/sensor structural integration

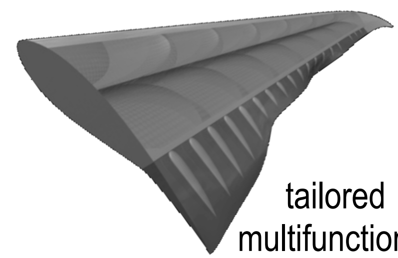
Aerodynamic Shaping
- Low interference external bracing
- Passive/Active wave drag reduction concepts

Adaptive Aeroelastic Shape Control
- Continuous control effector(s) for mission-adaptive optimization

Benefit/Pay-off

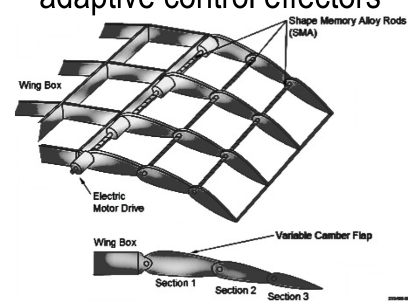
- 20% wing structural weight reduction
- Wave drag benefits tradable for weight or other parameters
- Concepts to control and exploit structural flexibility
- Optimal AR increase up to 50% for cantilever wings, 100% for braced


active controls
load alleviation


tailored
multifunctional

passive/active
advanced aerodynamics

adaptive control effectors



TC3.1(FY17): Community Noise -12 dB cum, TRL 5

Objective

Aero | Struc | Prop | Clean | Quiet

Explore and develop aero-structural-acoustic technologies to directly reduce perceived community noise with minimal or no impact on performance

Technical Areas and Approaches

Active Flow Control

- Mechanically simple high-lift systems with low mass flow

Airframe Noise

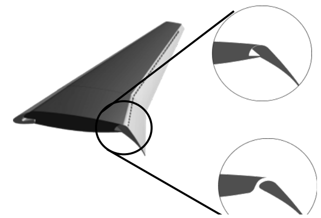
- Flap and slat noise reduction concepts

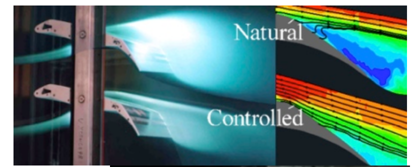
Acoustic Liners and Duct Propagation

- Multi-degree-of-freedom, low-drag liners

Benefit/Pay-off

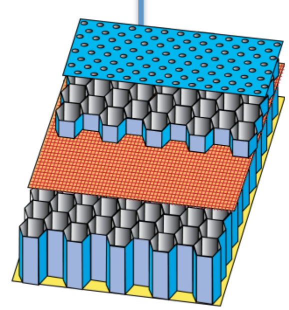
- 12 dB cum noise reduction
- Liner and non-AFC high-lift system technology have early insertion potential
- Benchmark aero-acoustic performance of a realistic AFC-based, reduced part count, reduced weight high-lift system

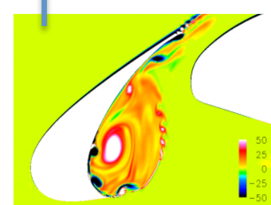


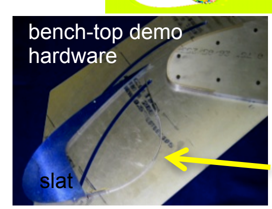


AFC-based high-lift concepts

flap/slat noise reduction concepts







main element

cove filler assembly

two-layer liner concept

TC4.1(FY17): Low NOx, Fuel-Flex Combustor CAEP6 -80%, TRL 3

Objective

Aero | Struc | Prop | **Clean** | Quiet

Explore and develop technologies to directly enable efficient, clean-burning, fuel-flexible combustors compatible with high OPR (50+) gas-turbine generators

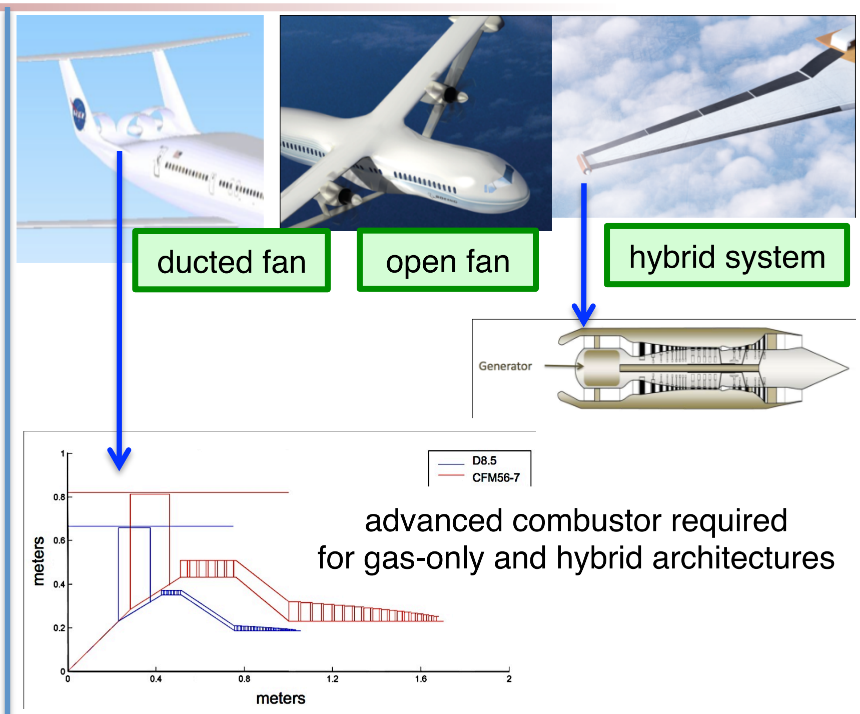
Technical Areas and Approaches

Fuel-Flexible Combustion

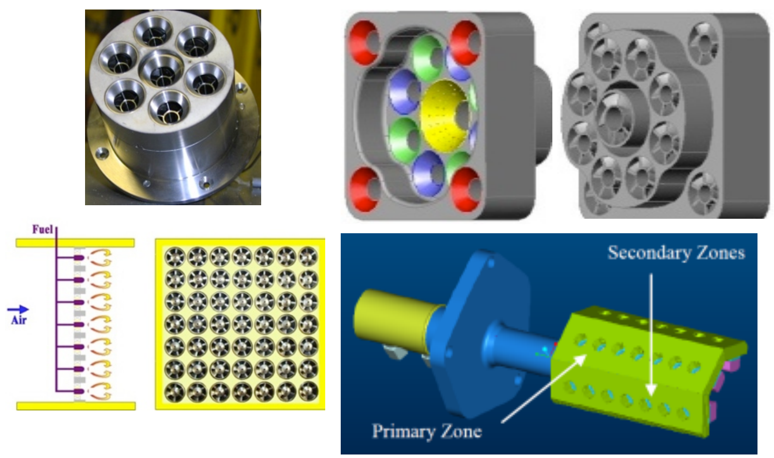
- Injection, mixing, stability

Benefit/Pay-off

- Low emissions: NOx reduction of 80% at cruise and 80% below CAEP6 at LTO, and reduced particulates
- Compatible with thermally efficient, high OPR (50+) gas generators
- Compatible for gas-only and hybrid gas-electric architectures
- Compatible with ducted or unducted propulsors



low emission flametube concepts



TC4.2(FY19): Compact, High OPR (50+) Gas Generator TRL 4

Objective

Aero | Struc | Prop | Clean | Quiet

Explore and develop material, aerodynamic, and control technologies to enable compact gas-turbine generators with high thermal efficiency to directly reduce fuel consumption

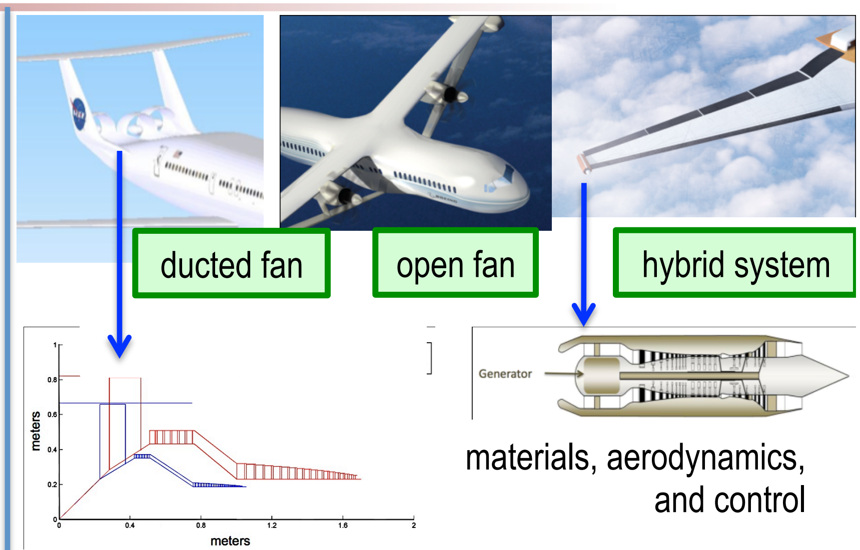
Technical Areas and Approaches

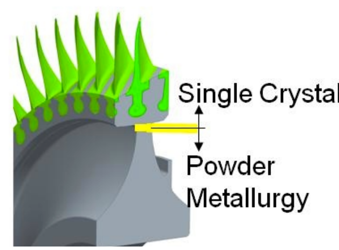
Hot Section Materials
- 1500F disk & coatings
- 1500F capable non-contacting seal

Tip/Endwall Aerodynamics
- Minimize losses due to short blades/vanes
- Minimize cooling/leakage losses

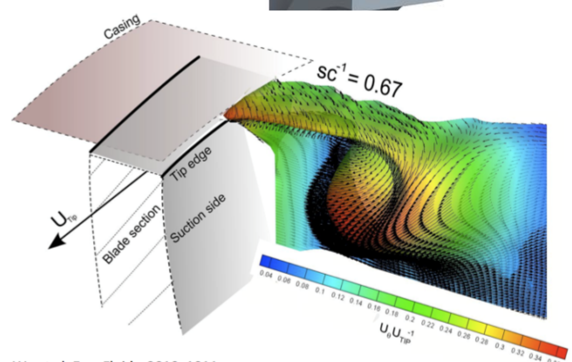
Benefit/Pay-off

- Advanced compact gas-generator core architecture and component technologies enabling BPR 20+ growth by minimizing core size
- Thermally efficient, high OPR (50+) engines





1500 F, bonded hybrid disk concept



Tip/endwall aerodynamic loss mitigation

Wu et al. Exp. Fluids, 2010, 1011
Miorini et al., J. Turbomachinery 2012, AIAA Journal 2012

TC5.1(FY17): Electric Motor Power Density +100%, TRL 3

Objective

Aero | Struc | **Prop** | Clean | Quiet

Explore and develop electric system materials and increase the power density of a superconducting electric motor contributing to game-changing hybrid gas-electric propulsion

Technical Areas and Approaches:

Electric System Materials

- Low ac loss superconducting materials
- Multifunctional structures integrating power system

Electric Components

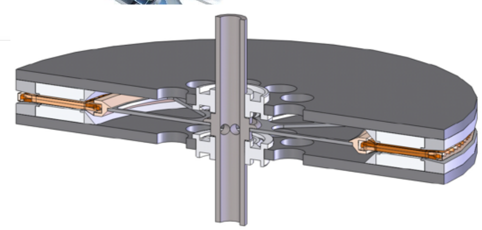
- High power density superconducting motor
- High power density non-cryogenic motor

Benefit/Pay-off:

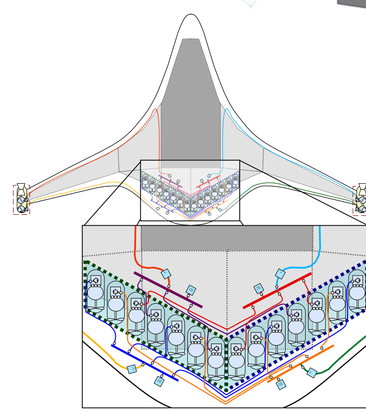
- Will help enable the paradigm shift from gas to hybrid gas-electric propulsion
- Hybrid gas-electric propulsion will help reduce energy consumption, emissions, and noise

Gas turbine-battery hybrid

Superconducting turboelectric distributed propulsion



High Power Density, Non-cryogenic Motor



Propulsion power grid architecture

TC6.1(FY16): Integrated BLI System net vehicle benefit, TRL 3

Objective

Aero | Struc | Prop | Clean | Quiet

Explore and develop technologies to enable highly coupled, propulsion-airframe integration that provides a net vehicle system-level energy efficiency benefit

Technical Areas and Approaches

Aerodynamic Configuration

– Novel configurations and installations

Distortion-Tolerant Fan

– Integrated inlet/fan design robust to unsteady and non-uniform inflow

Propulsion Airframe Aeroacoustics

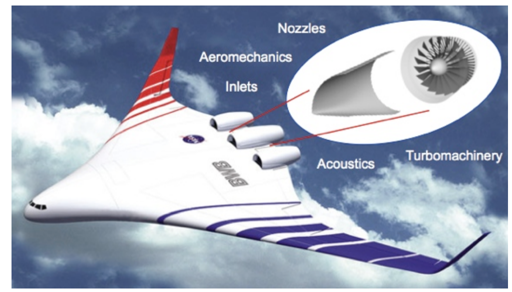
– Inlet distortion/short duct inlet aeroacoustics

Benefit/Pay-off

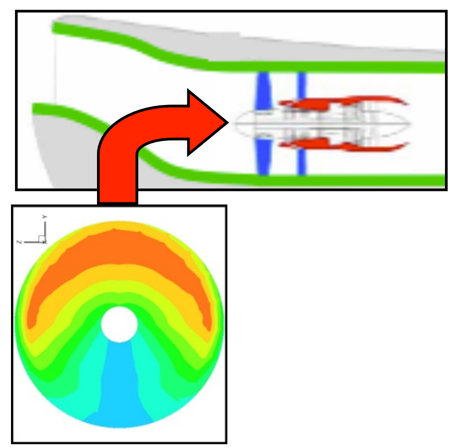
– Demonstrates a net system-level benefit for BLI propulsion system integration; applicable and beneficial to a variety of advanced vehicle concepts

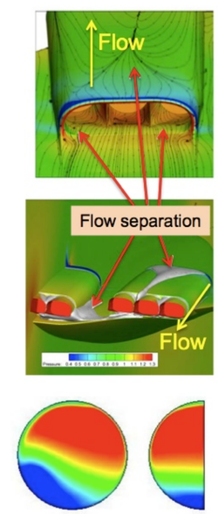
– Distortion-tolerant fan technology and acoustics characterization relevant to near-term, conventional short-duct installations

boundary-layer ingestion for drag reduction



distortion tolerance required for net vehicle system benefit





TC7.1(FY15): Alternative Fuel Emissions at cruise, TRL n/a

Objectives

Aero | Struc | Prop | **Clean** | Quiet

Explore the potential of alternative fuels to reduce the impact of aviation on air quality and climate, and their impact on performance.

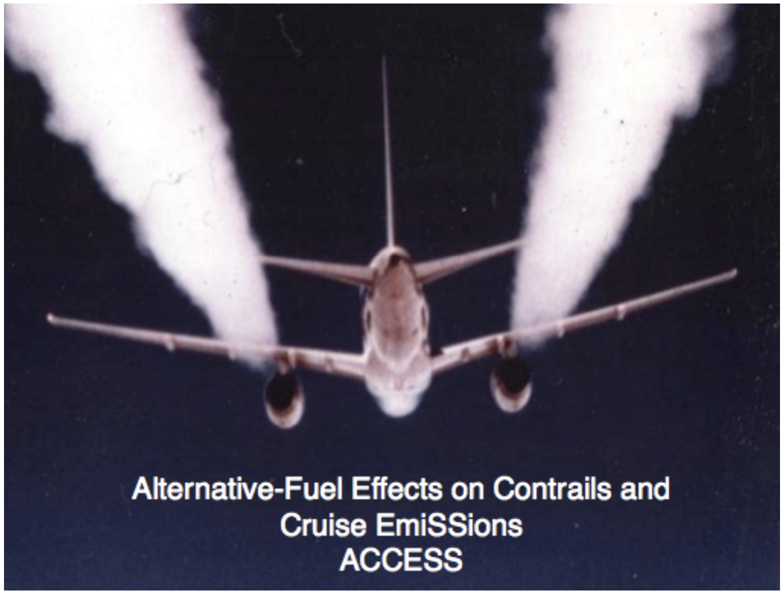
Technical Areas & Approaches

Emission & Performance Characterization

- Flight tests
- Ground tests
- Laboratory tests

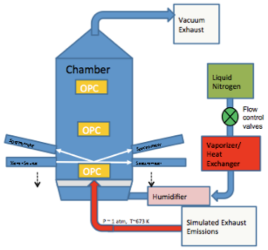
Benefit/Pay-off

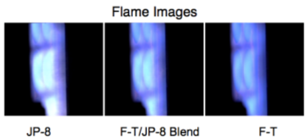
- Will dramatically reduce the impact of aviation on the environment (gaseous, particulates, and contrails)
- Will support standard-setting organizations by providing important and timely data



leverage ground tests from prior years

lab studies





Selected FY12 Technical Highlights

- Successful Completion of Advanced High Lift Leading Edge Technology for Laminar Flow Wings
- Validation Test for Improved Structural Efficiency Design Tool: EBF3PanelOpt
- Development of Polyimide Foam for Aircraft Sidewall Applications
- Mission Variable Camber Flap Control System for High Lift and Cruise L/D ratios
- Subsonic Ultra Green Aircraft Research (SUGAR) N+4 Study

“AMELIA” CESTOL Study in the 40’x80’ NFAC Wind Tunnel at NASA Ames

PROBLEM

Lack of aerodynamic and acoustic validation data for active flow control Cruise Efficient Short Takeoff and Landing (CESTOL) configuration

OBJECTIVE

Acquire aerodynamic and acoustic validation data for the Advanced Model for Extreme Lift and Improved Aeroacoustics (AMELIA) low-noise CESTOL configuration developed by Cal Poly under an NRA

APPROACH

- Design a Hybrid Wing Body (HWB) configuration capable of meeting NASA’s noise, fuel burn, emissions, and field length goals.
- Perform large-scale test in the NASA Ames 40’x80’ wind tunnel to examine:
  - Low-speed, high-lift aerodynamic performance for take-off & landing
  - Over-the-wing Turbine Powered Simulators at two engine heights
  - Acoustic characteristics of jet-blown circulation control for powered lift
  - Multiple flow visualization techniques

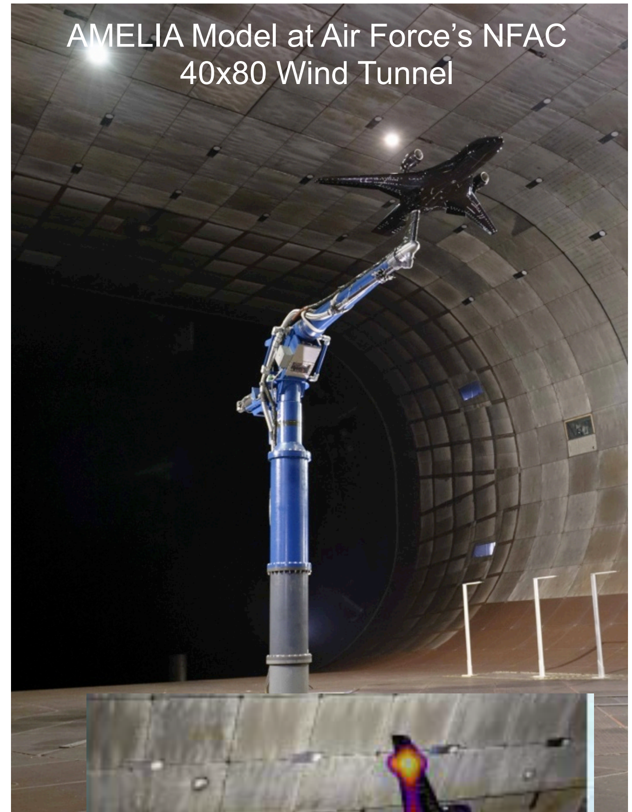
RESULTS

- Wind tunnel test successfully completed February 2012
- Test provided low-speed experimental force and moment data as well as surface pressure data for the AMELIA model
- Test also provided direct measurement of skin friction using an oil interferometry method, smoke and oil visualization data, and acoustic data
- Experimental results being correlated with CFD predictions

SIGNIFICANCE

- First wind tunnel test of a full-span model incorporating leading and trailing edge blowing wing circulation control and engine simulators.
- Test data will be utilized to improve CFD tools for advanced configurations.
- Circulation control can enable lighter high-lift systems and reduced field length capability. Alternatively, lift benefits can be traded for reduced weight/drag aircraft.

AMELIA Model at Air Force’s NFAC 40x80 Wind Tunnel



Array beamform map of active lift regions

POCs: D. Marshall, T. Jameson (Cal Poly); R. Fong, N. Burnside, C. Horne (ARC)

Open Rotor Propulsion System Assessment

PROBLEM
Open rotor propulsion systems possess the potential for dramatic reductions in fuel burn; however, the acoustic signatures of the new generation of blade geometries need to be investigated

OBJECTIVE
- Assess fuel burn and community noise of an open rotor system on an advanced, single-aisle (737-class) transport
- Investigate the efficiency benefit at different cruise Mach numbers and/or mission lengths

APPROACH
Utilize experimental data collected from GE's GEN-1 open rotor blade geometry scale model test, in concert with NASA robust noise and propulsion analysis techniques, to predict fuel burn and noise levels

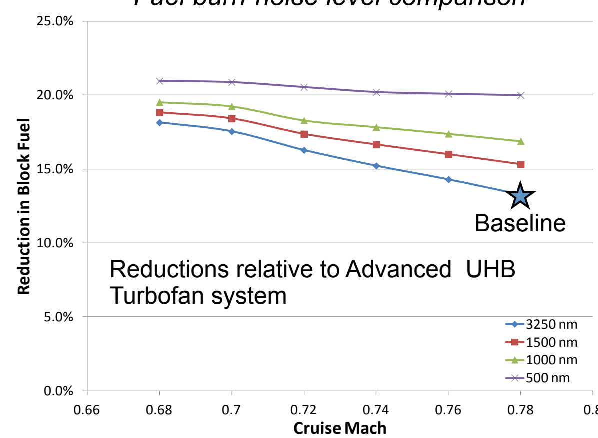
RESULTS
- Open Rotor system shows potential to be more fuel efficient than ducted turbofan but has a smaller noise margin
- Open Rotor efficiency increases with lower cruise Mach number and/or shorter range

SIGNIFICANCE
Results provide industry and regulatory community data to help make informed decisions on open rotor fuel efficiency and noise trade-offs. Results being used by ICAO in the assessment of future noise reduction standards

Single-aisle airplane w/rear-mounted open rotors

	Adv UHB Turbofan	Adv Open Rotor
Fuel Burn re 1998 Reference Vehicle	-27%	-36%
Chapter 4 Cumulative Noise Margin	-24 dB	-13 dB

Fuel burn-noise level comparison



Sensitivity of efficiency benefit to Mach/Range

Research team: Bill Haller (GRC); Mark Guynn (LaRC), Jeff Berton, Eric Hendricks, & Mike Tong (GRC), Phil Arcara (LaRC)

Aerodynamic Design Review of Boundary Layer Ingesting Distortion Tolerant Fan

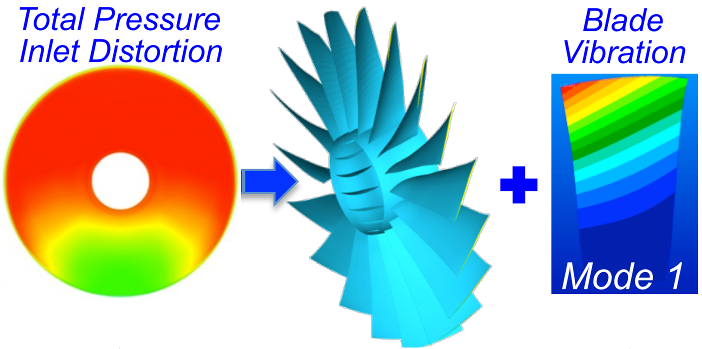
PROBLEM
Enable more efficient propulsion through a substantial reduction of more than 50% in the amount of fuel burned by commercial aircraft.

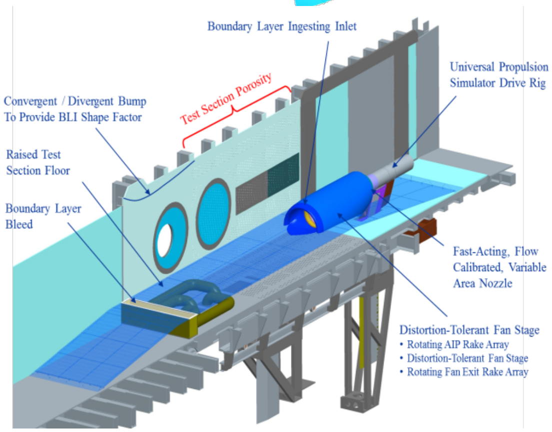
OBJECTIVE
Achieve increased aircraft propulsive efficiency and reduced weight and drag by ingesting large amounts of available fuselage boundary layer air flow and embedded propulsion within the airframe.

APPROACH
Design, fabricate, and test a large-scale, multi-use, boundary layer ingesting (BLI) distortion tolerant inlet-fan configuration consisting of a single BLI inlet coupled with a 22” diameter distortion-tolerant fan in the NASA GRC 8’X6’ Transonic Wind Tunnel.

RESULTS
Aerodynamic design review of the BLI inlet-fan completed. Mechanical design of hardware has been initiated. Fan fabrication to be completed in FY13 for wind tunnel entry in FY14. Conceptual design of experiment completed and test preparation efforts also well underway.

SIGNIFICANCE
This experiment will represent the first-ever test of a BLI fan designed to handle inflow distortions. The data will serve to validate the tools and methodologies being developed that are critical to designing next-generation, propulsion systems that are tightly integrated with the airframe. Methodologies developed already being used by P&W to design next-generation geared turbofans with short inlets.





Research team: D. Arend, S. Thomas, M. Bakhle, G. Herrick (GRC), T. S. Reddy/U. Toledo, UTRC (Partner)

Cessna STAR-C^2 Protective Skin for Composite Airliners

PROBLEM

Composite structures are currently overdesigned to account for requirements beyond structural loads (such as hail damage, lightning strike protection). This results in significant increases in structural weight and thus, fuel burn.

OBJECTIVE

Reduce fuel burn through use of a protective skin concept to reduce weight directly through materials (reduced primary structure and multifunction protective skins) and facilitating natural laminar flow.

APPROACH

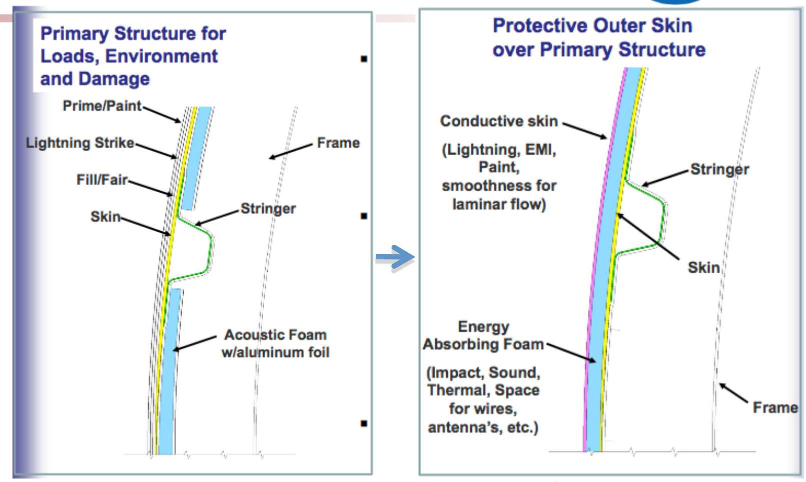
Develop a protective skin with layers that have material properties that provide performance for aesthetics, smoothing, EMI & lightning protection, and energy absorption; use available and affordable materials; and assemble and install skins efficiently to achieve the maximum weight savings & highest performance improvement by enabling natural laminar flow.

RESULTS

- Defined requirements for impact testing, smoothing and aesthetics, direct and indirect lightning strike damage criteria. Identified potential materials
- Fabricated and tested 173 test articles; down selected articles for Phase II testing on performance in impact and lightning strike tests and weight requirement.
- Based on today's materials, Star-C^2 concept is marginally feasible. Feasibility will increase when new materials become available that combine properties and functions identified from this research.

SIGNIFICANCE

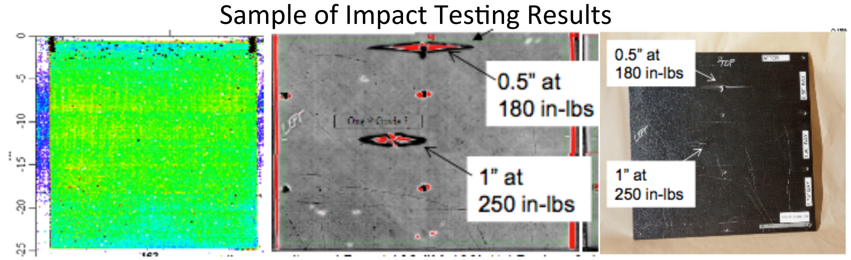
Projected advances in traditional composite materials are not sufficient to meet 70% fuel burn reduction goal. STAR-C^{2}concept provides additional 7% (of 33% total) weight reduction for a 2035 airliner and achieves 69% reduction.



Current Design

Cessna's Proposed Skin

Sample of Impact Testing Results

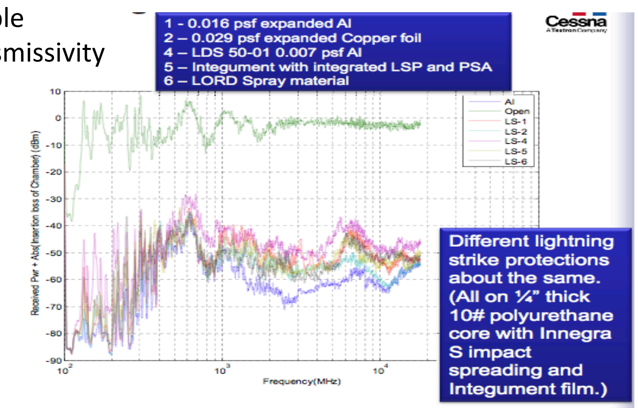


Thermography Before Impact

Thermography After Impact

Optical Image After Impact

Sample Transmissivity



COTR: Mia Siochi (LaRC)

FY2012 APG: AAFEX-II Experiment and Data Dissemination Completed

PROBLEM
Need to determine effects of synthetic alternative fuels on aircraft emissions.

OBJECTIVE
Perform static aircraft engine testing using Hydrotreated Renewable Jet (HRJ) and other fuels to determine effects on engine performance and emissions. Also, examine methodologies for particle sampling to assist the SAE–E-31 Aircraft Particle Measurement Subcommittee in developing a standard particle sampling technique.

APPROACH
Utilize the NASA DC-8 aircraft at the Dryden Operational Facility in Palmdale, CA, to perform emissions testing using various alternative fuels and a JP-8 reference fuel and obtain gaseous, solid, and aerosol samples for analysis at 1, 30, and 150 meters downstream of the aircraft engine exhaust.

AAFEX-II Test

RESULTS
- Conducted more than 30 hours of engine testing in April 2011 with participants from NASA LaRC, DFRC, and GRC; AFRL; FAA; AEDC; MST; NAVY AESO; EPA; P&W; GE; R-R; UTRC; PSU and several particle measurement instrument companies.
- Obtained gaseous and particulate emissions for neat HRJ, HRJ/JP-8 blend, JP-8, F-T low sulfur, and F-T high sulfur fuels.
- Results showed that HRJ fuel and blends had minor effects on gaseous emissions. No effect on engine performance was evident within the accuracy of the data. As observed in AAFEX I, volatile and non-volatile combustion generated particulates were substantially reduced when the engine was operated on HRJ Fuel.
- Held a workshop in January 2012 in Nashville, TN, after the AIAA Aerospace Sciences Meeting, where all participants presented their findings. Held an invited session at the AIAA JPC Meeting in August 2012 where four invited presentations compared the results from the AAFEX I and II experiments.

SIGNIFICANCE
- Results will be used to determine effects of several alternative fuels and fuel sulfur on engine performance and emissions.
- Particle sampling methodology experiments will directly support SAE E-31 subcommittee development of a standard for particulate sampling.

Fixed Wing Project Research Team

NASA Ames, Dryden, Glenn, and Langley Research Centers

Three main components

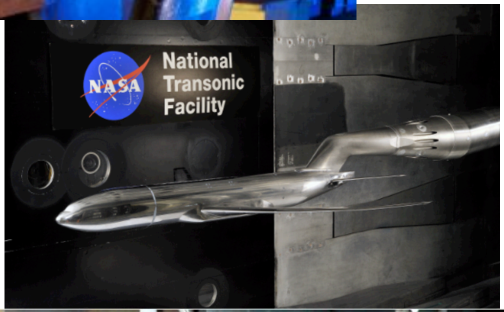
- NASA in-house research
- Research with partners (Gov. Agencies, Industry, Univ.)
- Sponsored research by NASA Research Announcement (NRA)

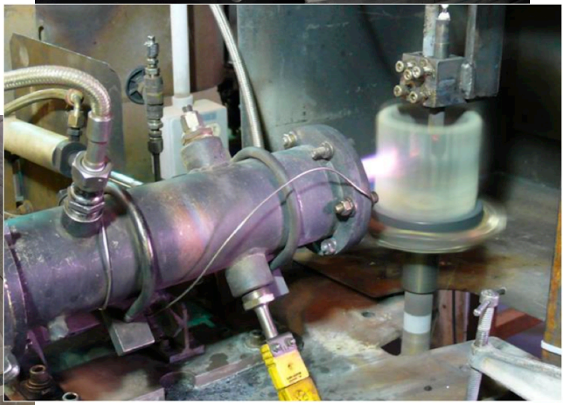
Major Fixed Wing Activities for FY2013

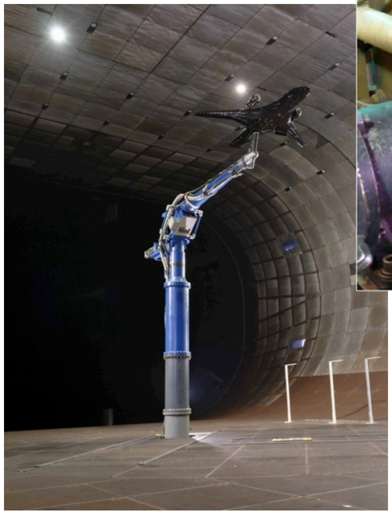
- Complete second round of FAST-MAC experiments at NTF to understand flow control and circulation control benefits to low-speed high lift and high-speed efficiency at high Re numbers
- Acquire X-56A flight vehicle from AF after shakedown flight tests and work on developing advanced and open (non-proprietary) control capability
- Complete evaluation of STAR-C2 (smooth thermal absorbs reflects – conducts cosmetic) multifunctional aircraft skin/structure concept
- Conduct ACCESS-1 flight tests using biofuels
- Prepare for Truss-Braced Wing Aeroservoelastic Test with Boeing at the LaRC TDT
- Conduct PAI/BLI Aerodynamic Test on MIT/D8 concept at LaRC 14x22
- Complete fabrication of distortion-tolerant fan for embedded engines and prepare for testing in GRC 8x6 tunnel in FY14-15
- Perform systems assessment of noise and emissions for Turboelectric Distributed Propulsion concept
- Test Common Research Model (CRM) to validate Active Damper Capability at LaRC NTF
- Strategize, plan, and execute next round of NRA awards

Concluding Remarks

- Addressing the environmental challenges and improving the performance of subsonic aircraft
- Undertaking and solving the enduring and pervasive challenges of subsonic flight
- Understanding and assessing the game changers of the future
- Nurturing strong foundational research in partnership with industry, academia, and other Government agencies







Technologies, Concepts, and Knowledge

NASA